Considerations for Developing Invasive Exotic Plant Monitoring

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Plant communities and invasive exotic plants were initially identified as high priorities for monitoring within the Prairie Cluster Prototype Program. During the design phase of the monitoring program, we focused on developing plant community monitoring, emphasizing 1) the predominant prairie and savanna/woodland associations, 2) high quality or unique sites of special concern, and 3) areas undergoing active restoration and management. While our current plant community monitoring effort provides some information on exotic trends within the predominant vegetation types, it is unlikely to provide early warning of new exotic threats because it does not emphasize ecotones, degraded or disturbed sites, or invasion corridors. Consequently, we are beginning work to develop invasive exotic plant monitoring for the Prairie Cluster parks. In a related effort, several of these parks identified invasive plant inventories as a top need within the Heartland I&M Network. We initially developed inventory plans for these parks as part of the Inventory Full Study Plan for the Heartland Network. The ideas presented below stem from these concurrent and developing efforts.

Setting Objectives for Invasive Exotic Plant Monitoring

In our initial scoping sessions with park resource managers, it became clear that there was a management need for several different types of information relating to invasive exotic plants. In surveying the range of current and potential exotic threats to the Prairie Cluster parks, it was also evident that, depending upon the stage of invasion, particular exotic species would present different sampling challenges. From our perspective, it was important to clarify those distinctions, in order to design monitoring that was both feasible and would provide relevant data back to management.

In Table 1, we describe the first three stages of exotic invasion that managers may observe. In each case, both the information need and the sampling design issues are somewhat different. For example, when the management objective involves detecting new invasions, or finding exotic populations in the early stages of invasion, the sampling design must be appropriate to searching for a rare occurrence. On the other, for a well-established invasive species that may dominate the vegetation in some areas, monitoring efforts should be focused on those areas where the information need is greatest. It may be a case of proving the obvious to collect intensive monitoring data in areas that are already dominated by an invasive species. Monitoring efforts might be better directed toward identifying invasion fronts or protecting sensitive areas.

Building on the framework developed for this workshop, Table 2 lists specific questions that may be addressed under each broad monitoring topic.

Table 1. Species distribution and sampling design considerations in the initial stages of exotic invasion.

Management Objective	Monitoring Objective	Invasive Species Distribution	Sampling Design Considerations
Eternal Vigilance -- Detect & control invasive exotics before establishment	Early detection of new invasions	Species is known to occur regionally or on adjacent lands, but has not yet been confirmed within park. If present at all, distribution is sparse, limited in extent and may vary from sparse individuals to dense patches	Rare event Emphasis on extensive searching, attention to boundaries/corridors, rapid assessment
Search and Destroy -- Locate and control establishing populations	Location of establishing populations	Species has been found in the park in small, localized patches. Finding and controlling patches might prevent large-scale invasion. Distribution is somewhat limited in extent and may vary in intensity from sparse individuals to dense patches	Moderately rare event Grid-based or stratified random sampling with higher selection probabilities in areas likely to be invaded
Man the Trenches -- Target limited control resources toward highest priorities	Map invasion front; identify Areas for targeted management	Species is established and abundant in some areas. Targeted control to protect sensitive areas, prevent further invasion, and reduce the rate of spread along invasion fronts. In some areas no longer feasible to locate and control individual patches	Moderately frequent to common event Variable sampling intensity to locate and map invasion fronts

Table 2. Invasive exotic inventory and monitoring objectives.

Inventory and Mapping

- Where within the park do invasive exotic plant species currently occur?
- How are they distributed?
- How abundant are they?

Monitoring

1. Prevention and Early Detection

- Which invasive exotic species are likely to threaten the park within the near future?
- Where are likely invasion corridors adjacent to and/or extending into the park?
- Which areas within the park are most likely to be threatened by invasive exotics?

2. Target Limited Control Resources Toward Highest Priority Threats

- Where can control efforts be concentrated to prevent further invasion or reduce the rate of spread?
- Can invasive species life history or habitat attributes be used to help establish lines of defense?
- Where within the park do invasive exotics currently threaten native plant communities, unique habitats, rare species, etc.?

3. Measure Effect of Control Programs on the Target Exotics/Invasives

- How effective are control efforts?
- Is the target exotic re-sprouting or re-establishing from a seedbank?

Caution: early in the development of control measures a controlled, experimental approach may be more appropriate to answer questions of effectiveness.

4. Measure Effect of Control Programs on Recovery of the Natural System Impacted

- Are native species rebounding following exotic species control?
- Are control efforts resulting in negative, unintended consequences for native plant species?

In the case of control efforts coupled with native species restoration:

- Are the native species seeded (or transplanted) into the restored area becoming established?
- Is the restored area approaching the desired 'model community' composition?
- Is the restored area resistant to subsequent exotic invasion?

5. Determination of Patterns & Trends on Landscape & Regional Scales

Lessons borrowed from Plant Community and Rare Plant Monitoring

Nested Frequency Sampling

Monitoring change in plant communities is a core component of the Prairie Cluster Monitoring Program. For long-term monitoring of grazing and fire regimes, both changes in species diversity and abundance shifts in dominant species are of interest. Our basic monitoring protocol employs estimates of foliar cover in large sample frames to best capture species richness and diversity. However, given the high inter-annual variability in aboveground primary production in prairie ecosystems, frequency measures may provide a better indication of changes in abundance than foliar cover.

We recently tested a nested, multi-scale method for measuring frequency in tallgrass prairie plant communities (DeBacker et al., in prep.). Beginning with a search of the smallest quadrat, and proceeding sequentially through three larger quadrat sizes, species are recorded once on first occurrence (Figure 1). Because the quadrats are nested, occurrence in a quadrat implies occurrence within all larger quadrats of that nest. Frequency data are generated for each species at multiple spatial scales. Selection of the most appropriate scale for examining changes in frequency of a particular species is based on the data, with frequencies of 63-86% considered ideal (Curtis and McIntosh 1950) (Table 3). We found nested frequency plots to be effective for estimating abundance of the dominant species, as well as for moderately common species. In this trial, 40 nested quadrats were sufficient to detect changes in frequency of 12-15%.
Nested frequency quadrats may work well for simultaneously estimating the abundance of multiple invasive exotic species, particularly if those exotic species are moderately common to abundant within the communities of interest. A nested frequency approach would also allow concomitant collection of abundance data for the entire plant community, including native species and exotics that have not been targeted for monitoring.

Figure 1. Plant Community Sampling Design for the Prairie Cluster Prototype Program, including nested frequency quadrats.

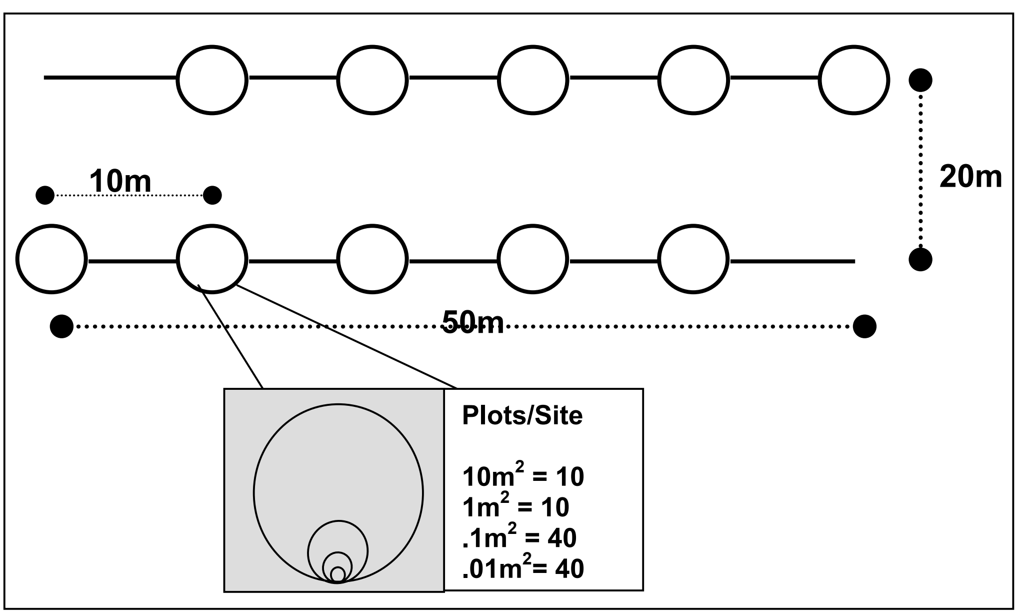

Table 3. Optimal frequency sampling scale (shaded) for the ten most abundant species. Data from nested frequency sampling trial; Tallgrass Prairie National Preserve, Kansas (DeBacker et al., in prep.).

Species	Common Name	Quadrat Size				
		$10m^2$	$1m^2$	$0.1m^2$	$0.01m^2$	Point
Andropogon gerardii Vitman	Big bluestem	100.0%	100.0%	80.8%	46.7%	1.4%
Schizachyrium scoparium (Michx.) Nash	Little bluestem	100.0%	93.3%	78.3%	47.9%	5.0%
Bouteloua curtipendula (Michx.) Torr	Side-oats grama-grass	100.0%	90.0%	64.2%	45.0%	1.7%
Ambrosia psilostachya DC.	Western ragweed	100.0%	86.7%	90.8%	59.6%	0.5%
Sporobolus asper (Michx.) Kunth	Tall dropseed	100.0%	83.3%	35.8%	14.6%	1.1%
Carex spp	Sedges	100.0%	80.0%	59.2%	32.1%	0.7%
Amorpha canescens Pursh	Lead-plant	100.0%	76.7%	46.7%	13.3%	0.2%
Vernonia baldwinii Torr.	Western ironweed	96.7%	70.0%	14.2%	2.1%	0.1%
Panicum virgatum L.	Switchgrass	93.3%	70.0%	32.5%	14.2%	0.1%
Sorghastrum nutans (L.) Nash	Indian grass	86.7%	63.3%	44.2%	21.3%	1.3%

Adaptive Sampling

Adaptive sampling designs refer to sampling procedures in which site selection is partially determined by variables of interest that are observed during the survey. The aim is to make use of distribution characteristics of populations to obtain more precise estimates of abundance or density than would be obtained with conventional designs of equivalent sample size (Thompson 1992). A secondary benefit is an increase in the yield of interesting observations. Adaptive designs are particularly well suited for populations that tend to aggregate in fairly small portions of the study region, especially when the location of these aggregations cannot be predicted prior to the survey (Thompson 1992).

We undertook a pilot project to evaluate whether an adaptive sampling design could improve the precision of density estimates for a federally endangered plant species, Missouri bladderpod (*Lesquerella filiformis*), occurring at Wilson's Creek NB (Thomas et al., in prep). We used a two-stage adaptive cluster sampling technique (Salehi and Seber 1997), to compare the precision obtained from adaptive sampling to a more conventional approach (two-stage random sampling). Over the three years of comparison, adaptive sampling resulted in a 5 to 16-fold reduction in sampling error. An example illustrating a two-stage adaptive design is shown in Figure 2.

Adaptive sampling designs may prove useful for some invasive exotic monitoring questions, especially when the objective is to detect exotic populations in the early stages on invasion.

Rare Plant Decision Support Framework

Within the Prairie Cluster Prototype Program, we have developed in-depth monitoring protocols for two federally listed rare plant species, and are in the process of designing less intensive monitoring for approximately 38 state listed rare plant species. As a part of that effort, we are developing a decision support framework to assist in: 1) selecting appropriate monitoring strategies for multiple rare plant species, 2) prioritizing and allocating monitoring effort among multiple species and information needs, and 3) adjusting the monitoring emphasis as species' status and information needs change (DeBacker et al., in prep.). In some respects, monitoring multiple invasive exotic species may be similar to monitoring a number of rare species. Shared requirements include:

- an initial need for basic inventory work and information gathering
- an objective system of setting priorities and documenting assumptions
- a flexible monitoring approach that is responsive to changing threats and information needs

Figure 4 provides a schematic of how these components might be combined to build an invasive exotic monitoring program.

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Figure 2. Examples of two-stage, stratified random (A) and adaptive (B) sampling designs. Both methods employed a sampling grid divided into primary units, with each primary unit consisting of 25 secondary units. In the case of adaptive sampling, a subset of primary units is first randomly selected; within each selected primary unit, 1 secondary unit was randomly selected to serve as a 'seed cell'. If the seed cell meets a selection criterion (10 or more plants present, in this example), adaptive sampling is initiated in adjacent cells (rook's moves), continuing until no new cells are added to the network or the boundaries of primary sampling unit are reached. In those primary units where a network of multiple cells are sampled, the values are averaged to produce a mean and variance estimate for the primary unit.

A. Two-Stage Random Sampling **B. Two-Stage Adaptive Sampling**

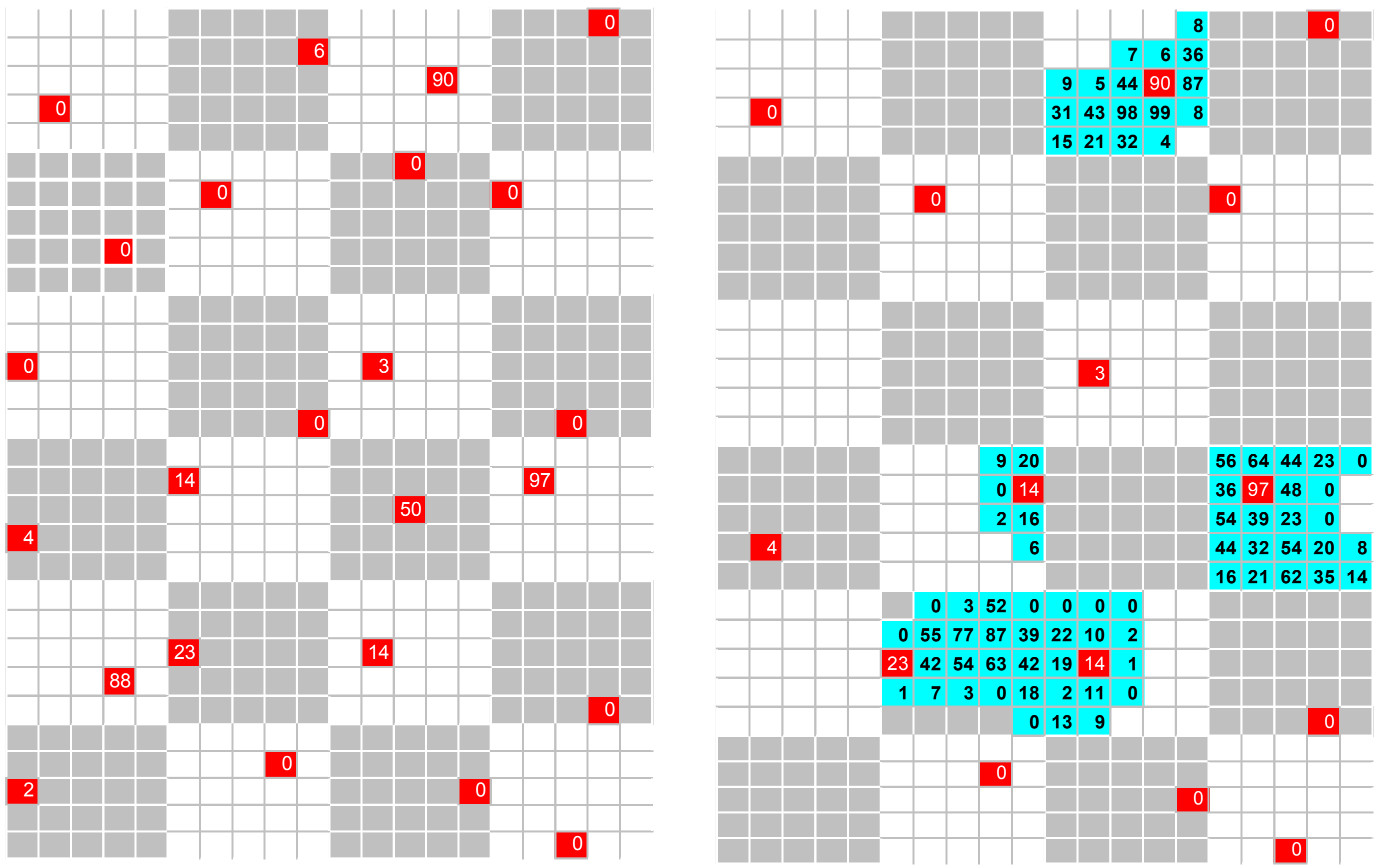

Figure 3. Schematic diagram showing steps in the process of developing a monitoring plan for multiple rare plant species (DeBacker et al., in prep.).

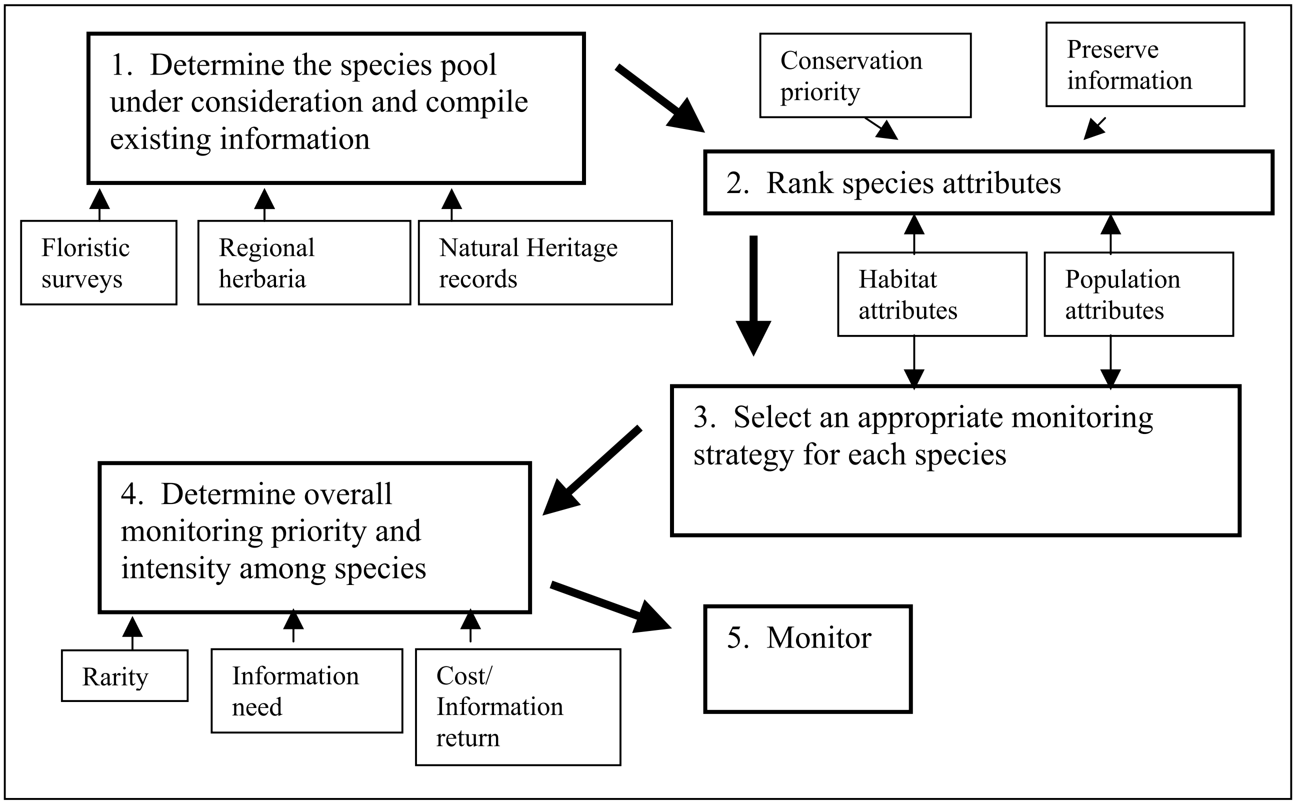

Figure 4. Schematic diagram of the potential steps and components of an exotic plant monitoring program.